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Sea Kraits (Squamata: *Laticauda* spp.) as a Useful Bioassay for Assessing Local Diversity of Eels (Muraenidae, Congridae) in the Western Pacific Ocean

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Collection of eels of the families Muraenidae and Congridae is often hampered by logistical and procedural difficulties. Sea kraits of the genus *Laticauda* may be useful bioassays for moray and conger eels in the western Pacific Ocean. Some widely distributed species of *Laticauda* appear to prey exclusively on eels, and these eels are readily palpated from snakes after they return to land to digest their prey. We removed 79 eels from 276 snakes on the island of Efate, Republic of Vanuatu, during November and December of 2000. Species diversity inferred from these eels was markedly different from the diversity inferred from eels from Vanuatu deposited in the Australian Museum, perhaps reflecting differential abilities of snakes and humans to capture certain eel species. This bioassay technique is inexpensive and logistically simple and may prove complementary to more traditional collecting methods.

ASSESSMENTS of the species diversity, ecology, and conservation status of many organisms are dependent on data gleaned from museum collections (e.g., Shine, 1996; Ricklefs, 1997; Heyer et al., 1999), but these studies may be biased if collections are not representative of all species present. Humans tend to collect certain species disproportionately relative to their actual abundances, often resulting in uneven representation of some taxa in collections and biological surveys relative to their actual abundances in the wild (Gaston, 1991; Blackburn and Gaston, 1995; McKenzie et al., 1995).

Biases in collection and observation are compounded by difficult working conditions in some environments or by cryptic behavior of target animals. Eels can be especially difficult to collect, because of their secretive habits and tendency toward nocturnal activity (Shipp, 1986). Sea kraits (Squamata: Elapidae: *Laticauda* spp.) may offer a useful method of collecting moray and conger eels (Muraenidae and Congridae, respectively). Six species of sea krait are currently recognized, and three of these species prey almost exclusively on eels (Saint Girons, 1964; Pernetta, 1977; Voris and Voris, 1983). Unlike the viviparous sea snakes, sea kraits are amphibious. They forage in aquatic habitats but return to land for activities such as basking, digesting, mating, and ovipositioning (Pernetta, 1977). Three species (*Laticauda colubrina*, *Laticauda laticaudata*, and *Laticauda semifasciata*) of eel-eating sea kraits are widely distributed through the western Pacific Ocean and, thus, are most likely to be useful as bioassays for eels.

A number of factors increase the feasibility of sampling eels from sea kraits. These snakes can achieve high densities, especially on rocky islets free from mammalian predators. For example, approximately 2300 *L. colubrina* use a 4-ha islet offshore from Viti Levu, Fiji (Shetty, 2000). Second, although these snakes are venomous, five of six species (the exception being *L. semifasciata*) are generally docile. Finally, ingested eels are usually obvious as elongate bulges in captured snakes. Gentle palpation of the snake's abdomen results in regurgitation of the eels.

MATERIALS AND METHODS

The Republic of Vanuatu is an archipelago northeast of New Caledonia in the western Pacific Ocean. The island of Efate is situated in the southern part of the archipelago. Our study site encompassed three rocky shorelines (totaling approximately 700 m of shore) near Paonangisu Village on the north coast of Efate, as well as four small (0.25–15 ha) nearshore islets.

We encountered sea kraits along the shore at night, and in rock crevices by day. We captured snakes by hand, placed them in cotton bags, and palpated eels from snakes the following day. We marked and released all snakes after data collection. Eels removed from snakes were photographed beside a tape measure. We later identified eels from photographs using reference materials and keys at the Australian Museum (AM) in Sydney.

RESULTS AND DISCUSSION

We captured 276 snakes of three species (*L. colubrina*, *L. laticaudata*, and *L. frontalis*) during

TABLE 1. NUMBERS OF EELS FROM STOMACHS OF SEA KRAITS (*Laticauda*) FROM EFATE, VANUATU, AS COMPARED TO VANUATU SPECIMENS IN THE AUSTRALIAN MUSEUM (AM). The first column lists the eel taxon (identified to genus, species, or morphospecies), the second column lists the number of individuals removed from the stomachs of sea kraits in November and December 2001, and the third column lists the number of individuals represented in the AM, collected between 1973 and 1997.

Taxon	From snake stomachs	From museum collection
Family Congridae		
Ariosoma scheelei	0	1
Conger cinereus	6	2
Gorgasia sp.	0	1
Heteroconger hassi	0	1
Heteroconger sp.	0	2
Family Muraenidae		
Echidna delicatula	8	0
Echidna leucotania	0	2
Echidna nebulosa	0	3
Enchelycanassa cf. *canina*	1	0
Enchelycore bayeri	0	2
Gymnomuraena zebra	1	0
Gymnothorax cf. *buroensis*	2	5
Gymnothorax chilospilus	3	2
Gymnothorax enigmaticus	1	1
Gymnothorax fimbriatus	3	3
Gymnothorax fuscomaculatus	0	3
Gymnothorax flavimarginatus	0	6
Gymnothorax cf. *gracilicauda*	7	0
Gymnothorax margaritophorus	1	2
Gymnothorax melatremus	0	1
Gymnothorax monostigmus	0	1
Gymnothorax ruppelliae	0	3
Gymnothorax thyrsoideus	0	1
Gymnothorax undulatus	5	0
Gymnothorax zonipectis	0	3
"plain brown" *Gymnothorax* sp.	9	?
"barred greenish" *Gymnothorax* sp.	4	?
"large mottled" *Gymnothorax* sp.	1	?
Gymnothorax spp.	12	7
Scuticaria tigrina	2	0
Uropterygius marmoratus	0	1
Uropterygius polyspilus	1	0
Unknown eel	10	0

November and December 2000 (~ 28 days of fieldwork). We removed and photographed 79 eels from 71 snakes. Eels were discarded after photography, because we did not hold export permits for preserved specimens. We identified seven genera and 13 species of eels from snake stomachs (Table 1) and were able to identify 40 specimens to species and 69 to genus. Subsequent experience demonstrated that this level of identification would have increased if dichotomous keys were available in the field, because we were unable to distinguish many key characters from our photographs. Even large eels can be sampled using this method; three female *L. colubrina* disgorged conger eels (Congridae: *Conger cinereus*) over 1 m in length. Three snakes from which we had palpated prey were recaptured within three to five days with full stomachs, indicating that palpation and/or regurgitation of prey is unlikely to adversely affect future predatory success.

The species diversity of eels removed from snakes differed from diversity inferred by examination of Vanuatu eels held in the AM (Table 1). This may indicate that snakes are more successful at locating some species than are humans, although most collecting expeditions are taxonomically general rather than specifically targeting eels. In fact, our total sample of 79 eels collected during one month of fieldwork exceeds the 66 eels in the AM collected in Vanuatu by conventional means during four ichthyological collecting trips during May or June of 1973, 1975, 1996, and 1997 (the AM also contains 20 eels removed from the stomachs of *Laticauda* in Vanuatu by H. Cogger in 1984 and 1993, but 90% of these were identified only to family). Diversity of Vanuatu eels in the AM included specimens of 20 known species, as well as a few specimens identified only to genus, whereas our sample from *Laticauda* stomachs included 13 known species and some eels identified to genus or family. Discounting our unidentified morphospecies and those eels identified only to family or genus, only six species of eels from Vanuatu were sampled by both humans and snakes (Table 1). Thus, although sampling of eels by humans may result in greater species richness among specimens, sampling eels from snakes is likely to substantially increase estimates of alpha diversity.

Our results reiterate previous observations that snakes may sample certain taxa more effectively than humans. For example, an allegedly extinct Australian lizard (*Tiliqua adelaidensis*) was recently rediscovered after several specimens were found in the guts of elapid snakes (*Pseudonaja textilis*; Armstrong and Reid, 1993). Similarly, mammalian taxa that are rarely recorded in faunal surveys of Sumatran forests (such as the Sunda pangolin, *Manis javanica*) were frequently found inside reticulated pythons (*Python reticulatus*; Shine et al., 1998).

Our method does have disadvantages. In Vanuatu, snakes do not take a random sample from the overall eel species assemblage. We often observed snowflake eels (*Echidna nebulosa*) foraging on reef flats, but this species was not identified among snake prey. To gain a clearer picture of the overall eel community, removal and identification of eels from snake stomachs will be most useful when combined with more standard methods for sampling eels. Furthermore, eels are often partially digested when removed from snakes, making identification difficult. To counter this, we recommend that collecting effort be concentrated along shorelines just after dark, when snakes with newly ingested prey move from aquatic to terrestrial environments. Our observations indicate that, if prey items are removed from these snakes soon ($<$ 8 h) after capture, eels are relatively intact and readily identified.

There are several benefits to our technique. The method is sustainable, so long as prey are not sampled from the same snakes too often. Because sea kraits have been observed foraging from shallow reefs to depths over 45 m (Greer, 1997), they may sample eels from a great range of depths. Regular sampling of snakes could provide indices of temporal variation in relative local abundances of both snakes and eels. Finally, the method is relatively simple, so that local people can be recruited to gather data and preserve specimens in the absence of professional ichthyologists. Recruitment of local people may help foster conservation ethics, and ultimately increase awareness of marine conservation issues.

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